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On July 20, 1989, Diamond Materials, Inc. (DMI), began work on its SBIR Phase II program entitled "Development of High-Performance β-SiC Field-Effect Transistors." This program is funded by SDIO/IST and is monitored by the Office of Naval Research. During the first quarter of this program, work has concentrated on designing and installing engineering upgrades to DMI's β-SiC reactor. These upgrades include an inverted rotating platen and expansion of the gas control system to handle three different dopant source gases. Additionally, the gas plumbing system has been rebuilt to permit instant turn-on and turn-off of dopant gases in order to make p-n junction and doped/undoped junctions during *in situ* growth. It is anticipated that growth experiments into the formation of undoped β-SiC will begin early in the next quarter.

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FIRST QUARTER TECHNICAL REPORT

DEVELOPMENT OF HIGH PERFORMANCE β-SiC FIELD-EFFECT TRANSISTORS

Prepared by

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October 26, 1989

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FIRST QUARTERLY TECHNICAL PROGRESS REPORT

DEVELOPMENT OF HIGH PERFORMANCE ß-SiC FIELD-EFFECT TRANSISTORS

1. INTRODUCTION

DMI has been awarded an SBIR Phase II program entitled "Development of High Performance ß–SiC Field-Effect Transistors." This 24-month program officially started July 20, 1989. This Technical Progress Report summarizes the accomplishments made during the first three months of this program.

The ultimate goal of this Phase II program is to develop ß-SiC field-effect transistors (FETs). These ß-SiC transistors should be of good enough quality to enable, for the first time, measurement of ß-SiC transistor characteristics at high frequencies. To achieve these goals, DMI's Phase II program includes the following tasks:

1. Improve the quality of undoped monocrystalline ß-SiC films grown on TiC substrates.
2. Develop methods to *in situ* dope ß-SiC during CVD growth.
3. Evaluate and compare three different dielectrics as possible gate insulators for ß-SiC IGFETs.
4. Fabricate ß-SiC MESFETs.
5. Fabricate depletion mode and enhancement mode ß-SiC IGFETs using a previously optimized gate insulator.

2. ACCOMPLISHMENTS OF THE LAST QUARTER

Work during the first quarter has focused on completion of Task 1, "Upgrade the CVD Reactor" as described in the Phase II proposal. Figure 1 is a Gantt Chart of the Phase II program.

DMI's Equipment Group in Danvers, MA, has designed and installed most of the upgrades to DMI's ß-SiC reactor. Most of the designs were made by Ross Giammanco, DMI's Chief Equipment Engineer and Director of DMI's Equipment Group. Since the beginning of the program, the following enhancements have been implemented:

1. The number of process gases which can be controlled has been expanded. Gas handling hardware and mass flow controllers have been installed to accommodate

methyltrichlorosilane (MTS), UHP H_2, UHP Ar, triisobutylaluminum (TIBA), diborane, ammonia, and H_2. All gases are being obtained with purity of at least 99.999%.

2. During Phase I, DMI experienced difficulty flowing MTS through mass flow controllers, since the boiling point of MTS is 66°C. The MTS frequently condensed inside the mass flow controllers causing the controllers to malfunction. ß-SiC growth runs were periodically suspended to clean and reassemble the MTS lines. Therefore, the reactor in Phase II is being built to prevent excessive condensation of MTS in the feed lines. The stainless steel tubing and the mass flow controllers for both MTS and the triisobutylaluminum are being heated to maintain temperatures between 50 and 60°C during operation. These measures should maximize productivity and minimize contamination throughout the course of the Phase II program.

3. DMI's Advanced Equipment Group has designed, built, and installed a gas handling system to enabling the formation of hyper-abrupt p-n junctions or doped/undoped junctions during epitaxial growth. Dopant gases such as diborane are flowed through a mass flow controller and out to the vacuum pump in order to stabilize flow by pneumatic valves. The flow of diborane can then be immediately switched into the reactor in order to replace the flow of ammonia (donor dopant) or to create p-type doping atop a undoped layer. This immediate response gas flow system is similar to those which appear on commercial MOCVD reactors to provide *in situ* doping of III-V semiconductors.

4. Gas cabinets and additional bubblers have been purchased and installed to handle the additional dopant gases needed for Phase II.

5. The reaction vessel has been completely redesigned from Phase I. In Phase I, all the fused silica belljars were handmade by glassblowers. This made replacement of cracked belljars a very slow and expensive procedure. For Phase II, DMI will use an improved a concentric belljar system using standard sized silica tubes.

6. Substrates are suspended face down on an inverted susceptor just as in Phase I. However, in Phase II, the susceptor can be rotated at speed between 0 and 60 rpm during film growth.

7. A new susceptor face plate assembly has been received. It was proposed that a solid TiC face plate would be used to reduce any chemical reactions between a graphite face plate and the TiC substrate surface. However, due to TiC machining limitations, DMI will instead coat graphite face plates with TiC by CVD from sources of titanium tetrachloride and ethylene. If all surfaces of the graphite face plate are coated with a 5 µm thick TiC layer, chemical reactions between the face plate and the TiC substrate should be eliminated.

During the first three months, DMI was scheduled to obtain the SAGE thermochemical computer program from its European vendor (see Figure 1). However, purchase of SAGE has been postponed until DMI receives payment of its first invoice on this Phase II program. DMI is currently awaiting payment of an invoice dated August 31, 1989, for $70,323.37 to cover the costs of the reactor upgrade. However, DMI does not anticipate that this delay will significantly impede meeting the goals of the next quarter.

During the last three months, DMI's Danvers Equipment Group has completed construction of DMI's baseline activated reactive evaporation reactor (ARE). The ARE reactor is a highly versatile production machine which can coat a variety of materials with areas up to 5" in diameter. Using Company funds, DMI is building the ARE reactor to develop a scaled-up process to produce c-BN thin-films. However, this same reactor will also be used in this Phase II program to deposit thin-films of AlN and MgO to determine their usefulness as gate dielectrics for ß-SiC IGFETs.

3. GOALS FOR THE NEXT QUARTER

During the next three months DMI plans to achieve the following:

1. Purchase and install the SAGE thermochemical computer program.
2. Resume growth experiments of heteroepitaxial ß-SiC. Improve the crystallographic quality of the film, i.e., eliminate second phase impurities and improve surface morphology.
3. Begin *in situ* doping experiments to quantify the diborane and ammonia versus resistivity relationships, respectively.
4. DMI also plans to begin design of a high temperature probe station to measure the electrical characteristics of ß-SiC test structures at elevated temperatures.

During the next quarter, the Principal Investigator, Dr. Richard Koba, and DMI's material scientist, Mr. Andrew Phelps, will both attend the Fall Materials Research Society Meeting in Boston, MA, to attend Symposium F, "Diamond, Boron Nitride, Silicon Carbide, and Related Wide Bandgap Semiconductors." It was decided that it would be better for DMI personnel to attend the MRS Meeting instead of the Electrochemical Society Fall Meeting because of the greater emphasis on ß-SiC and diamond at the MRS meeting.

In the next quarter DMI also will transfer its ARE reactor from its Danvers facility to its State College facility. This move will enable further enhancements in CVD film quality and allow the use of this ARE reactor in the development of AlN and MgO thin-films as required by Tasks 8 and 9 in the statement-of-work.

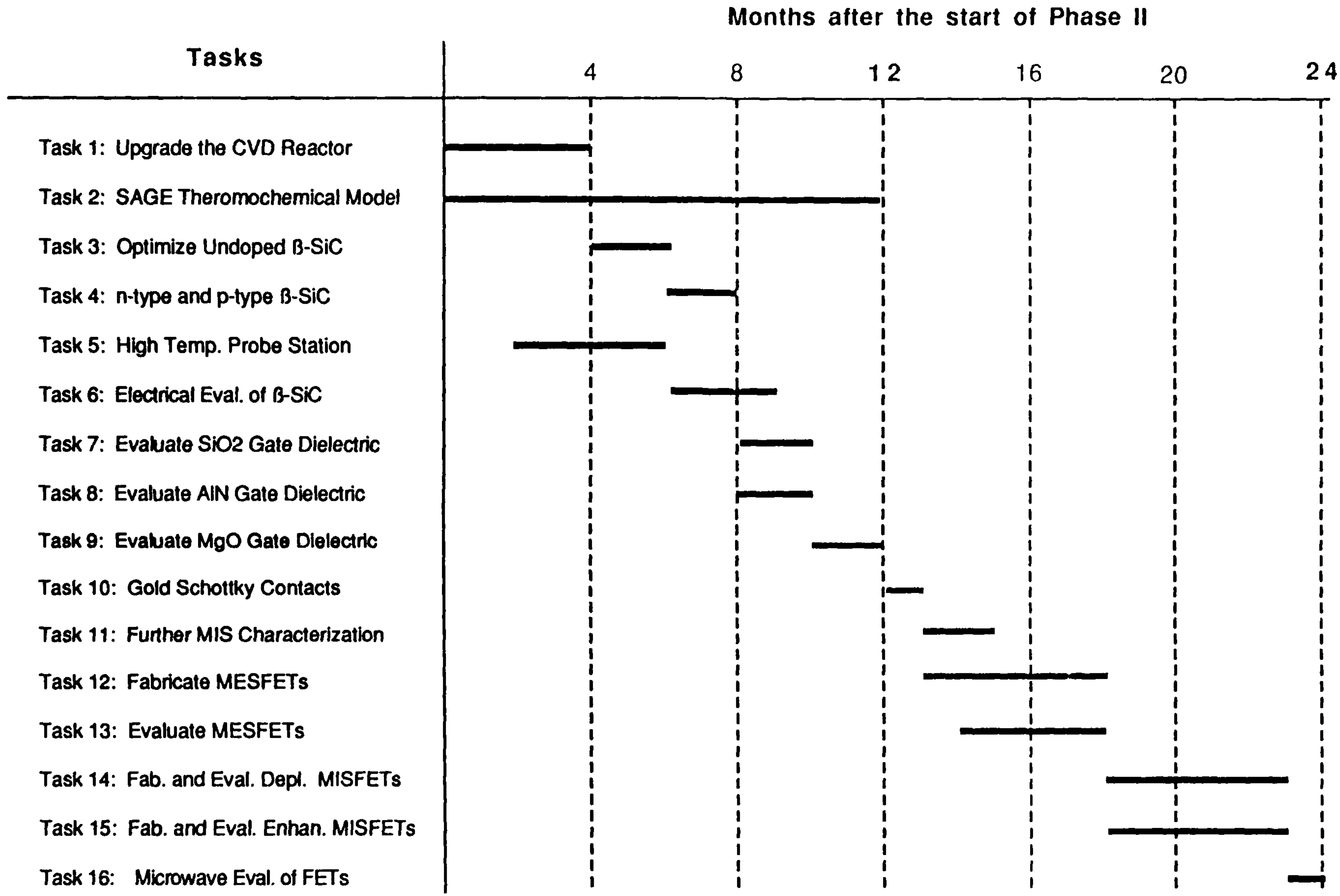

FIGURE 1. GANTT CHART FOR THE PROPOSED PHASE II PROGRAM.